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IRRIGATION WATER USE EFFICIENCY IN OLIVE TREES IN KAIROUAN, TUNISIA

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ABSTRACT

This study evaluated the technical efficiency and irrigation water use efficiency of olive farms in Tunisia, using Data Envelopment Analysis. In order to calibrate and validate the findings, data related to area, water use, water quality, cultivar, input, and yield were collected based on interviews from 45 irrigated olive farms in Kairouan Governorate. The results show that average input-oriented water use efficiency under the CRS and VRS specifications is 17.2% and 36.3%, respectively, indicating that the sampled olive farms could reduce the use of water by an average of 82.8% and 63.7% by improving the performance of irrigation systems. Also, it was found that there are large differences in irrigation water use efficiency between the CRS and VRS specifications. Consequently, this indicates that a number of olive farms can enhance overall efficiency by improving the scale of operation. In practical terms, this study provides significant insights for the olive growers in this study regarding the importance of removing scale inefficiency. Specifically, they need to consider the effects of water and soil quality on irrigated fields to improve the efficiency of irrigation water use.

Contribution/Originality: This study is one of very few to have evaluated irrigation water use efficiency in olive trees using Data Envelopment Analysis. The study provides significant insights for Tunisian olive growers regarding the importance of removing scale inefficiency.

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1. INTRODUCTION

Due to climate change and population increase, water is becoming scarcer and demand is increasing dramatically. In arid and semi-arid regions, the deficit of water is alarming and the situation will become worse in the future. The agriculture sector, which is a key pillar of the economy in developing countries, is the first user of freshwater. Indeed, the ratio of water use for irrigation is estimated to be about 80%. The Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, which was adopted by world leaders, recognized access to water and sanitation as human rights with the implementation of particular goals, namely SDG6.

In this context, the main challenge of governments is to provide safe water for the current population and next generation and to efficiently use water for agriculture. In Tunisia, the government has developed and adopted several strategies for effective management of water resources to maintain a balance between water demand and availability. Due to the importance of the agricultural sector and to maintain food security, irrigation is also promoted by the Tunisian government with the use of the water-saving equipment and an increase in water use efficiency.

Regarding productivity analysis applied to olive production, several studies are found in the existing literature. Using a parametric stochastic frontier approach, Tzouvelekas, Giannakas, Midmore, and Mattas (1999) and Tzouvelekas, Pantzios, and Fotopoulos (2001) estimated the technical efficiency and technological change in olive production of Greek farms. In Tunisia, Lachaal, Dhehibi, Chebil, and Karray (2004) and Lachaal, Karray, Dhehibi, and Chebil (2005) examined olive farms to measure technical efficiency and its determinants. Using a non-parametric Data Envelopment Analysis (DEA) approach, Cukur, Saner, Cukur, Dayan, and Adanacioglu (2013) employed both input- and output-oriented models on olive farms in Turkey. They found huge differences in efficiency among farms, with most operating below the optimal scale. In the olive sector in Turkey, Artukoglu, Olgun, and Adanacioglu (2010) compared efficiency between organic and conventional farming technology. Their estimation using an input-oriented model suggested that organic farms are more efficient than conventional farms. Ozden and Dios-Palmores (2016) investigated the effect of ownership structure on the efficiency of olive oil manufacturers in Turkey. Their study found that production managers with experience and extensive specialized training within the industry have, in combination, a positive effect. Using data collected from olive oil farmers in Greece, Niavis, Tamvakis, Manos, and Vlontzos (2018) evaluated the efficiency of extensive olive oil farming by implementing an input-oriented DEA model. They found significant variation in efficiency scores, suggesting considerable potential for improvement. They identified the enhanced utilization of subsidies, while land area related negatively to efficiency scores. Similarly, in Greece, Fousekis, Kourtesi, and Polymeros (2014) assessed the managerial efficiency of olive farms. They suggested that the ratio of family to total labor and the degree of intensification of production have a positive effect on efficiency. From a study focused on the heterogeneity of olive farms in Andalusia (Spain), Amores and Contreras (2009) suggest that the age of olive trees is one of the key factors explaining the variation in efficiency of olive farms.

Most studies have focussed on efficiency analysis, but investigation on the impact of irrigation is largely absent. Referring to the experience of the agriculture sector in Mediterranean countries, Hassine (2007) suggests a positive effect of irrigation on improvement in technical efficiency. Weissteiner, Strobl, and Sommer (2011) made a classification of olive farms in EU/Mediterranean countries based on farms' characteristics such as intensity, irrigation, and land productivity, yet discussion on the efficiency of irrigation is lacking. Fernández-Uclés et al. (2020) applied an output-oriented DEA model to olive farms in Tunisia. They found that the use of virtual social networks and outsourcing of ICT management are associated with higher efficiency, yet the impact of irrigation was not examined. Lachaal et al. (2004) suggested a positive impact of irrigation on the technical efficiency of Tunisian olive farms; however, water-use efficiency was not examined.

Therefore, the main objective of this work was to evaluate the irrigation water use efficiency of olive trees using DEA. Indeed, olive is an important agricultural product in Tunisia and contributes significantly to the trade balance. For this reason, the expansion of irrigation in olive-growing areas has been conducted to increase olive production. In this study, the DEA model was implemented using the program General Algebraic Modelling System (GAMS).

To our knowledge, this study may be the first to apply DEA to irrigated olive-growing farms in Tunisia.

2. MATERIALS AND METHODS

2.1. Study Area and Sample Size

We used data obtained by a survey conducted in Kairouan Governorate in 2016 (Figure 1). Kairouan Governorate in central Tunisia comprises 6,712 km^2 and a population of 570,559. Data on olive cultivation were drawn from 100 olive-growing farms who were randomly sent questionnaires. Of the 100 responses collected, 45 reported the use of irrigation from five administrative divisions in Kairouan Governorate; 66.7% (30 farms) were 5 ha or smaller, 15.6% (7 farms) were 5–10 ha, and 17.8% (8 farms) exceeded 10 ha.

In this study, one output and three input variables were used to estimate the frontier production function and efficiency scores in the DEA model. The output variable (Y) is olive production per ha. In addition, the three input variables are working hours per ha (L), the volume of irrigation water per ha (W), and intermediate costs per ha in Tunisian dinars (M), which include the remaining inputs such as fertilizer, pesticides, ploughing, transport, and so on.

2.2. Model

The DEA method, as used in this study, was proposed by Farrell (1957) and developed by others. This method measures relative efficiency and provides mathematical programming to construct a non-parametric piecewise frontier that includes input and output data. In the DEA model, one decision-making unit (DMU) manages relative to others in the sample and provides a benchmark for the best practice technology from the experience. Charnes, Cooper, and Rhodes (1978) proposed the DEA model for measuring technical efficiency under the constant returns to scale (CRS), which is called the CCR (Charnes, Cooper and Rhodes) model. Another DEA model is the BCC (Banker, Charnes and Cooper) model, used to measure technical efficiency under the variable returns to scale (VRS), which was proposed by Banker, Charnes, and Cooper (1984). In the present study, we utilized the CCR and BCC models of input orientation because a decrease in input level such as water and labor by keeping the output level (olive production) unchanged is the main objective in this study.

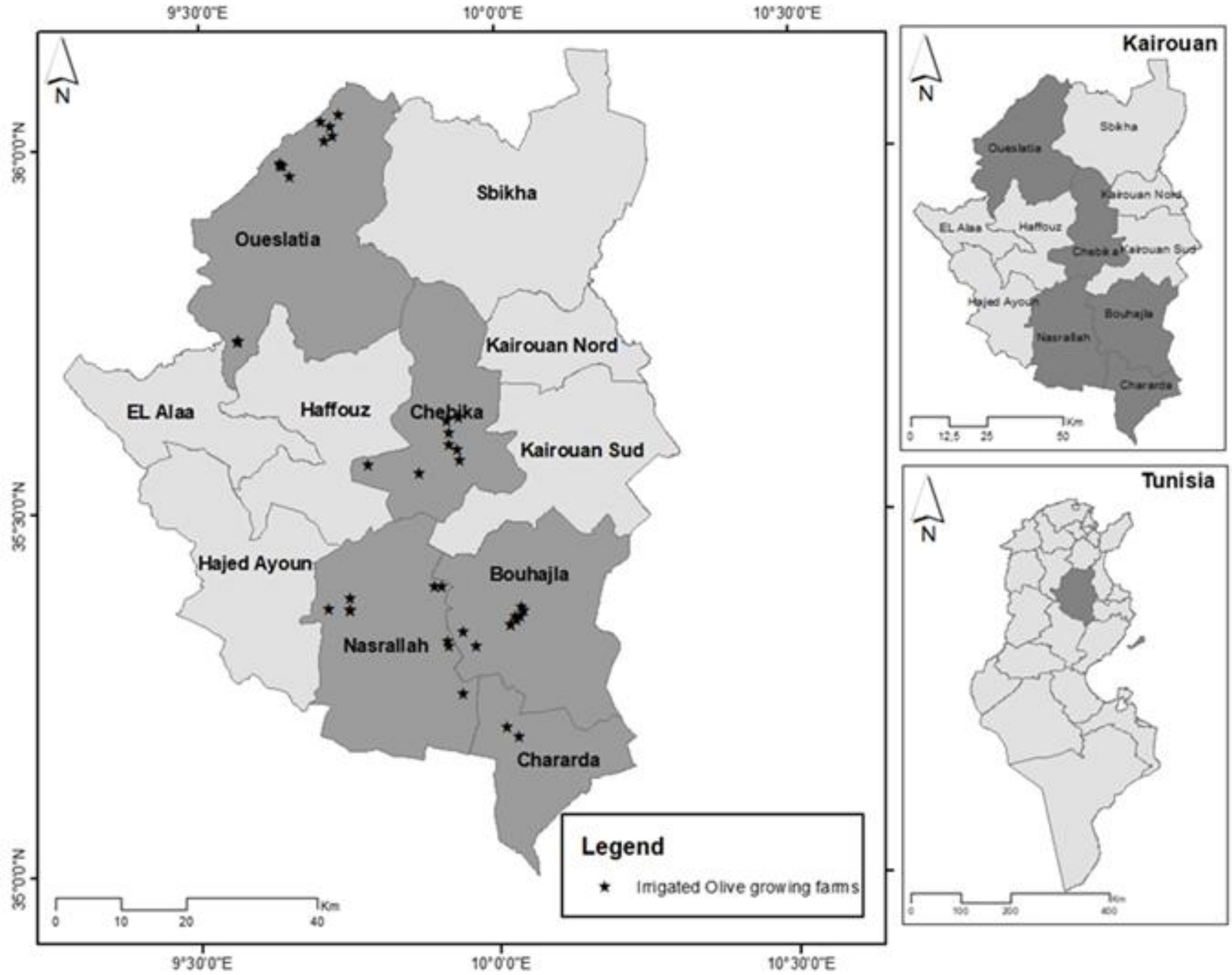

Figure-1. Map of study area.

The DEA considers the technological phases of production function. This is used to estimate a production frontier, convenient for decomposing production efficiency into technical and scale efficiencies without requiring estimates of input and output prices. As to *N* DMU *s*, all sample inputs and outputs are characterized by *K* and *M*, respectively. The technical efficiency (TE) of each DMU *s* can be defined as:

$$TE = \frac{\sum_m u_m y_{m,s}}{\sum_k v_k x_{k,s}}$$

where $x_{k,s}$ is the amount of the *k*th input of DMU *s*; $y_{m,s}$ is the amount of the *m*th output of DMU *s*, *v* is a vector of input weights [*K*×1], and *u* is a vector of output weights [*M*×1]. Efficiency is often scaled between 0 and 1, with complete efficiency scoring 1. The resulting efficiency score (the ratio of all outputs over all inputs) is maximized to select optimal weights subject to:

$$\frac{\sum_m u_m y_{m,s}}{\sum_k v_k x_{k,s}} \leq 1, \text{ for } k = 1,2,\ldots, K;\ m = 1,2,\ldots, M;\ u_m \geq 0;\ v_k \geq 0$$

where the first inequality indicates the efficiency ratios to be at least 1 and the second inequality indicates that the weights are positive.

First, derived efficiency measures are based on maximizing the ratio of all outputs over all inputs. To avoid an infinite number of solutions, the constraint $\sum_k v_k x_{k,s} = 1$ is imposed to provide the multiplier form of the input-oriented linear programming problem. This program of the input-oriented CCR DEA model can then be converted into the dual problem:

$$Min_{\theta,\lambda}\, \theta = \theta_{s0}$$

subject to

$$\sum_{s=1}^{S} \lambda_s y_{m,s} \geq y_{m,s0}$$

$$\theta_{s0} x_{k,s0} \geq \sum_{s=1}^{S} \lambda_s x_{k,s}$$

$$\lambda_s \geq 0$$

where θ_{s0} is a scalar and λ_s is a vector of S elements representing the effect of each DMU *s* in determining the technical efficiency of the DMU *s* under consideration, namely DUM_0; $x_{k,s0}$ is the input vector of the DUM_0, and $y_{m,s0}$ is the output vector of the DUM_0. The first constraint shows that production of the *m*th output by observation *s* cannot exceed any linear combination of output by all DUM's in the sample. The second constraint includes the use of inputs by observation *s*. θ is the technical efficiency score for the DMU *s* that satisfies: $\theta \leq 1$, where a value of 1 indicates the point on the frontier. $\theta = 1$ indicates that the DMU is technically efficient. Another basic DEA model is the BCC model. The CCR model is extended to the BCC model when not all DMUs operate at an optimal scale. This model adds a restriction on the $\lambda's$ to the CCR model. In other words, the input-oriented CCR linear programming problem can be modified into the BCC linear one by adding the convexity constraint ($\sum_{s=1}^{S} \lambda_s = 1$).

The concept of subsector efficiency is introduced into this basic DEA model to calculate the technical subsector efficiency score for the *k*th input. In this study, technical subsector efficiency for irrigation water, *w* is calculated for each olive-growing farm *s* by solving the DEA linear programming model. The irrigation water efficiency score for a given farm can be measured by looking at the possibility of reducing the water use *w* for a given set of all other inputs *k-w* and given output levels. Technically, this can be obtained by splitting the second constraint of that the basic DEA model into two inequities:

$$x_{k-w,s0} \geq \sum_{s=1}^{S} \lambda_s x_{k-w,s} \ , \quad \text{and} \quad \theta_{s0}^{w} x_{w,s0} \geq \sum_{s=1}^{S} \lambda_s x_{w,s}$$

Technical subsector efficiency for the irrigation water can be obtained by solving the transformed linear programming problem:

$$\text{Min}_{\theta,\lambda}\ \theta = \theta_{s0}^{w}$$

subject to

$$\sum_{s=1}^{S} \lambda_s y_{m,s} \geq y_{m,s0}$$
$$x_{k-w,s0} \geq \sum_{s=1}^{S} \lambda_s x_{k-w,s}$$
$$\theta_{s0}^{w} x_{w,s0} \geq \sum_{s=1}^{S} \lambda_s x_{w,s}$$
$$\lambda_s \geq 0$$

where θ_{s0}^{w} is the irrigation water efficiency score for the olive-growing farm$_0$. Like the basic DEA model, this CCR linear programming problem can be modified into the BCC linear one by adding the convexity constraint ($\sum_{s=1}^{S} \lambda_s = 1$). θ_{s0}^{w} can have a value between 0 and 1. If $\theta_{s0}^{w} = 1$, then the DMU *s* (olive growing firm *s*) under consideration is a frontier point, namely a technically efficient farm to use water for irrigation. Otherwise, if $\theta_{s0}^{w} < 1$, then the DMU *s* (olive-growing firm *s*) under consideration is inefficient to use the irrigation water, namely that this DMU can decrease its water used for irrigation.

GAMS was utilized for efficiency measurement in the DEA.

3. RESULTS AND DISCUSSION

3.1. Empirical Results

Table 1 presents the descriptive statistics of output and input variables used in this study. Olive production on average is 6.73 tons/ha. The volume of irrigation water per ha on average is 1,739.33 cubic meters (m^3)/ha, taking the minimum and maximum volume from 27.50 to 5,897.10 m^3/ha, respectively. Table 2 presents the average of the overall technical efficiency (TE) and irrigation water use efficiency (WE) in the sample. The average overall technical efficiency scores for the CRS DEA and VRS DEA models are 27.9% and 60.4%, respectively. This indicates that olive-growing farms at the current level of output could decrease all inputs on average by 72.1% (0.721 = 1 – 0.279) and 39.6% (0.396 = 1 – 0.604), respectively, to improve technical inefficiency. Four olive farms (one in Bouhajla and three in Oueslatia) were identified as fully technically efficient under the CRS specification, and eight (five in Oueslatia, two in Bouhajla, and one in Nasrallah) under the VRS specification. In addition, olive-growing farms located in the Oueslatia administrative division yielded higher average technical efficiency scores under both CRS and VRS. On the other hand, the average score of scale efficiency is 0.409. Four olive-growing farms were identified as fully scale efficient.

Table-1. Statistics for olive orchards in the study area.

Variable	Mean	Minimum	Maximum	Coefficient of variation
Y: Olive production (tons/ha)	6.73	0.2	41.8	1.00
L: Working hours (hours/ha)	43.88	3.3	155.0	0.72
W: Volume of irrigation water (m^3/ha)	1,739.33	27.50	5,897.1	0.75
M: Intermediate costs (TND/ha)	426.35	26.6	6,279.1	2.14

The average irrigation water use efficiency scores are 17.2% and 36.3% under the CRS and VRS specifications, respectively. This indicates that there is greater room for improvement in the inefficiency of irrigation water use than in technical efficiency because higher inefficiencies in the use of water compared to technical inefficiency were found in the surveyed area. Specifically, olive-growing farms could produce the current level of output by using 82.8% (0.828 = 1 – 0.172) and 63.7% (0.637 = 1 – 0.363) less irrigation water under CRS and VRS, respectively. Four olive-growing farms were identified as fully efficient in the use of water under CRS and eight under VRS. Farms located in the Oueslatia administrative division also showed the highest average efficiency scores in the use of water under both CRS and VRS. On the other hand, the average score of scale efficiency in the use of water was 0.457. Four olive-growing farms were identified as fully scale efficient.

Table-2. Frequency distribution of technical and irrigation water use efficiency scores.

Efficiency score (%)	CRS TE	VRS TE	CRS WE	VRS WE
	Number of farms	Number of farms	Number of farms	Number of farms
<10	17	0	36	22
11-20	12	2	0	4
21-30	6	5	0	1
31-40	1	8	2	1
41-50	1	3	1	0
51-60	1	5	0	4
61-70	0	8	0	1
71-80	0	1	1	0
81-90	2	3	0	4
91-100	5	10	5	8
Mean	0.279	0.604	0.172	0.363
Median	0.165	0.593	0.024	0.138
Standard deviation	0.313	0.271	0.322	0.396
Minimum	0.006	0.131	0.000	0.011
Maximum	1.000	1.000	1.000	1.000
Orchards	4	8	4	8
Mean SE	0.409		0.457	

Note: CRS TE: constant returns to scale technical efficiency. VRS TE: variable returns to scale technical efficiency. CRS WE: constant returns to scale water use efficiency. VRS WE: variable returns to scale water use efficiency. Orchards: number of perfectly efficient orchards. SE: scale efficiency.

Table-3. Efficiency. scores by administrative division.

Model	Mean	Minimum	Maximum
CRS TE			
Bouhajla	0.244	0.064	1.000
Nasrallah	0.197	0.039	1.000
Chebika	0.156	0.007	0.817
Oueslatia	0.523	0.027	1.000
Chararda	0.153	0.130	0.176
VRS TE			
Bouhajla	0.640	0.334	1.000
Nasrallah	0.513	0.132	1.000
Chebika	0.606	0.281	0.983
Oueslatia	0.657	0.194	1.000
Chararda	0.591	0.548	0.633
CRS WE			
Bouhajla	0.119	0.006	1.000
Nasrallah	0.085	0.004	0.723
Chebika	0.056	0.001	0.401
Oueslatia	0.446	0.002	1.000
Chararda	0.007	0.006	0.008
VRS WE			
Bouhajla	0.380	0.020	1.000
Nasrallah	0.211	0.017	1.000
Chebika	0.371	0.015	0.884
Oueslatia	0.523	0.011	1.000
Chararda	0.180	0.138	0.222

Table 3 shows efficiency scores by administrative division. Again, the highest average technical efficiency scores under VRS were found for olive-growing farms located in the Oueslatia administrative division in the north-western part of Kairouan Governorate. The lowest scores were for farms in the Nasrallah administrative division in the south-western part of the governorate. Farms in the Oueslatia administrative division had the highest average efficiency scores in the use of water under VRS, while the lowest were in the Chararda administrative division in the southern part of the governorate. In particular, olive-growing farms in Nasrallah and Chararda require a great deal of improvement regarding their inefficiency of irrigation water use.

According to the results of comparison of efficiency scores in the use of water, large differences were found between the CRS and VRS specifications. This indicates that a number of olive-growing farms could enhance overall efficiency by improving the scale of their operations. Specifically, farms in Kairouan could increase irrigation water use efficiency scores from 0.172 to 0.363 through elimination of 54.3% scale inefficiency. Consequently, substantial improvement is needed to increase irrigation water use efficiency.

To identify the relationship between the two efficiency measures, Spearman's correlation coefficient was calculated based on rankings of individual farm efficiency scores under the CRS and VRS specifications. Table 4 shows that scores for technical efficiency and irrigation water use efficiency under both specifications are positively correlated with each other and statistically significant at the 1% level. In particular, scores for technical efficiency and irrigation water use efficiency under CRS and VRS specifications, respectively, are highly positively correlated. Table 5 presents tests of mean differences in the average level of technical and irrigation water use efficiency under the CRS and VRS specifications. Statistical tests show that the mean difference between the two efficiencies is statistically significant. This result indicates that technical efficiencies in the sample are higher than those of irrigation water use.

Table-4. Spearman's rank-order correlation matrix.

	CRS TE	VRS TE	CRS WE	VRS WE
CRS TE	1.000			
VRS TE	0.642***	1.000		
CRS WE	0.923***	0.506***	1.000	
VRS WE	0.687***	0.929***	0.553***	1.000

Note: *** significance at the 1% level.

Table-5. *t*-test for difference in the means between technical and irrigation water use efficiencies.

Model	CRS TE-WE	VRS TE-WE
Mean difference	0.106	0.241
t-statistic	8.315***	9.041***
Standard deviation	0.085	0.179

Note: *** significance at the 1% level.

3.2 Discussion

From the analysis of inefficiency in this study we have obtained important findings. First, this study finds that olive-growing farms at the current level of output could reduce all inputs on average by 72.1% and 39.6%, respectively, to improve technical inefficiency, while they could produce the current level of output by using 82.8% and 63.7% less irrigation water, respectively, to improve the efficiency of irrigation water use. This is in line with the results of Mahdhi and Sghaier (2013) and Chebil, Frija, and Bahri (2014), who showed that considerable inefficiencies exist in irrigation water use for vegetable production in the region within Médenine Governorate in south-eastern Tunisia (Mahdhi & Mongi, 2013), and for wheat production in Chebika administrative division (Chebil et al., 2014). Meanwhile, the present study sheds light on the production of olive fruits, which are vital to the domestic economy. In the context of Tunisian olive growers, the findings from this study imply that improving irrigation scheduling and introducing more advanced technologies for irrigation water use can help optimize the performance of irrigation systems. Secondly, this study revealed that farms located in the Oueslatia administrative division have, on average, the highest technical and water use efficiencies under VRS specification while they are the lowest in the Charada and Chebika administrative divisions. This result indicates that olive-growing farms in these regions require considerable improvement in their technical and water use inefficiency. In particular, for Chebika, this is somewhat consistent with Chebil et al. (2014), who confirmed that wheat-growing farms in Chebika could produce the current level of output by using 59.5% and 56.8% less irrigation water under CRS and VRS specifications, respectively. The present study's results underscore the importance of removing scale inefficiency. More specifically, olive-growing farms in Chebika could increase the irrigation water use efficiency from 5.6% to 37.1% through eliminating 73.1% scale inefficiency, whereas wheat-growing farms in the region could enhance water use efficiency from 40.5% to 43.2% through eliminating 6.2% scale inefficiency. Therefore, these results imply that olive growers need to consider the effects of water and soil quality on their irrigated fields. In particular, for olive growers in Chebika, this should be carefully considered because of the large differences between water use efficiencies under the CRS and VRS specifications.

Thirdly, this study finds that technical efficiencies in the sample are higher than those for irrigation water use. Similar results were reported by Frija, Chebil, Speelman, Buysse, and Van Huylenbroeck (2009) in the Teboulba region within Monastir Governorate, located in eastern central Tunisia, and by Mahdhi and Mongi (2013) in the Zeuss-Koutine region within Médenine Governorate, south-eastern Tunisia, who showed that technical efficiencies are higher than those for water use. In the case of this study, the findings indicate that considerable inefficiencies occurred in the surveyed area and the sampled olive-growing farms must improve the inefficiency of irrigation water use because there are still opportunities for further improvement in water use efficiency. Therefore, both the sampled olive growers and agriculture policy makers should place considerable emphasis on investments in resources for a sophisticated irrigation system. Despite the aforementioned discussions and implications, this study has limitations. It used data based on interviews from 45 irrigated olive-growing farms in Kairouan Governorate; a comparison across governorates in Tunisia would be needed to generalize the findings from this study. Also, this study estimated frontier production function and efficiency scores in the DEA approach. Studies using the stochastic frontier analysis as an alternative approach and examining the results thus obtained would make the conclusions of this study more persuasive.

4. CONCLUSION

Our findings indicate that a number of olive-growing farms could enhance overall efficiency by improving their scale of operation. In practical terms, this study provides significant insights for the sampled olive growers regarding the importance of removing scale inefficiency. More specifically, they need to consider the effects of water and soil quality on irrigated fields to improve the efficiency of irrigation water use.

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